National Aeronautics and Space Administration

Marshall Space Flight Center

Path to Flight of Powder Bed Fusion Parts

JANNAF: Additive Manufacturing for Propulsion Applications

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Goals and Objectives

Develop Powder Bed Fusion as a reliable and routine alternative to traditional manufacturing methods for human-rated spaceflight hardware.

- Understand potential process failure modes
- Control the PBF process with proper specifications: industry, Center, or Agency
- Develop an enabling material property database
- Establish methods of part verification: lot acceptance, NDE, proof test methodologies
- Embrace future use of closed-loop process controls to ensure quality and reduce the burden of part-to-part acceptance

Flight Certification

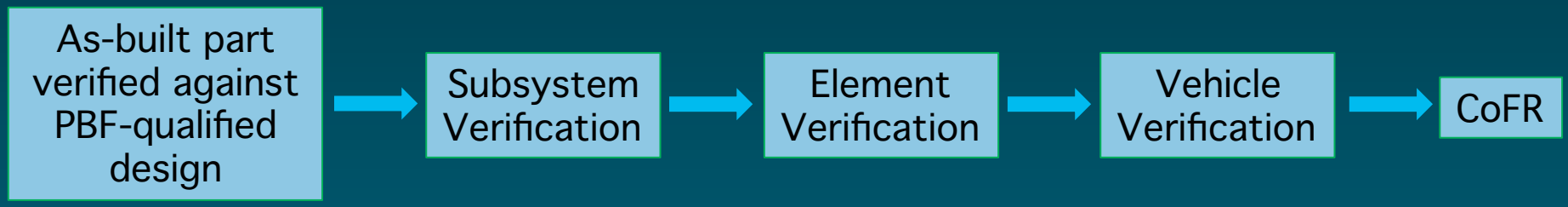
A working definition of certification:

Certification is the affirmation by the program, project, or other reviewing authority that the verification and validation process is complete and has adequately assured the design and as-built hardware meet the established requirements to safely and reliably complete the intended mission.

Flight Certification

1. Design Certification
2. As-built Hardware Certification

All hardware in the flight system will have verification of compliance leading to final Certification of Flight Readiness (CoFR).



What is the “design?”

The design is the baseline to which all as-built hardware is compared for verification and certification.

- Geometry definition, dimensional tolerances, etc.
- Materials and process specifications and controls
- Inspection requirements, including methods and acceptance criteria
- Required controls for cleaning, handling, storage, environmental protection
- “First article” evaluations, design qualification testing, part acceptance testing
- Assessments of part performance, structural and otherwise, both analytical and experimental

Design and Hardware Verification Methods

Standard Methods

- Design verification through analysis, qualification tests, occasional development testing
- As-built hardware verification through inspection, acceptance testing, materials and process controls

Non-traditional Methods

- Design verification through partial analysis, augmented by fleet-leader testing
- Design verification through limited quantity tests of margin through over-testing or testing with damage
- Hardware acceptance through quantitative proof testing
- Waiver and Deviation (beyond standard MRB actions)

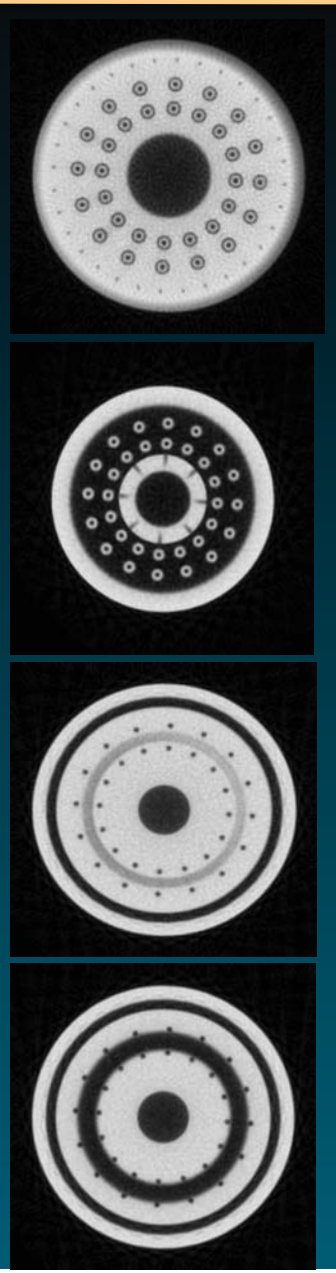
Challenges with PBF Verification Methods

Lack of standardization

- Physical part definition
- Materials
- Part Finishing Procedures
- Non-destructive Inspections

Lack of systematic understanding of process failure modes

- Mechanisms of process failure
- Characteristic defects



Flexible Certification Approach

Early part builds and acceptance tests occur in parallel with design and contribute to a growing materials database and understanding of the AM process.

- Individualized part development plans
- Part classification for customizable requirements
- Comprehensive first-article testing
- Thorough build-by-build lot acceptance testing and rigorous proof testing
- Fatigue testing as common lot acceptance procedure
- Frequent and direct interaction with vendors and full insight into vendor process controls

A Near-Term Path

Certification Path emphasizes early development, build, and test of hardware design to optimize performance and establish the material database.

Up-front development should reduce qualification time, cost, and complexity.

- *Performance Requirements*

  Part Definition and Performance Requirements

Verify that Design meets Requirements

- *Design Certification*

Develop prelim.design based on requirements

Build parts for prelim. evaluation and analysis.

Establish preliminary part development plans.

Perform preliminary performance analysis.

Lock Process

Verify that Part Performs as Designed

- *Part Acceptance*

Test material coupons from each part.

Inspect and destructively evaluate parts.

Proof Test
Flow Test
Burst Test
Vibe Test

First-Article Cut-up

Performance Acceptance Tests

Compressed DAC Cycle

Vendor Qualification and Machine Certification established prior to process lock-down.

Goal: Part Certification

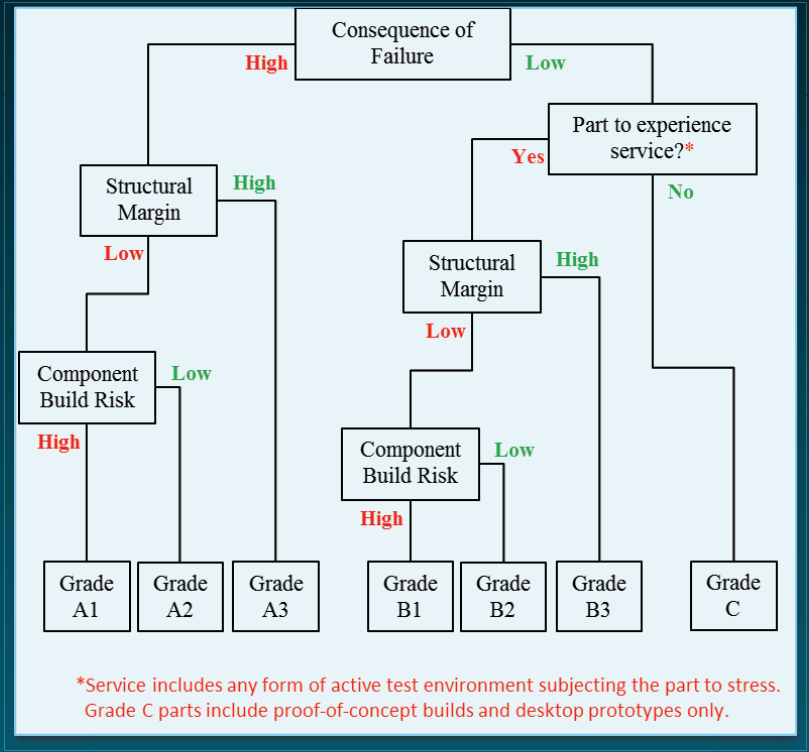
Near-Term Path: Part Development Plans

The Part Development Plan documents the implementation of the tailored engineering and quality control approach for the part.

- General Overview
- Design Overview
- Materials and Processes
- Structural Assessment
- Safety and Mission Assurance

Near-Term Path: Part Classification Approach

Verification requirements as a function of risk-based part grading



Consequence of Failure = High only if part failure results in

A. Creating a critical or catastrophic hazard,
B. Loss of life, or
C. Loss of national asset

Path to Flight Certification

Understand process failure modes

Provide for adequate process controls

Characterize process variability

- Material properties

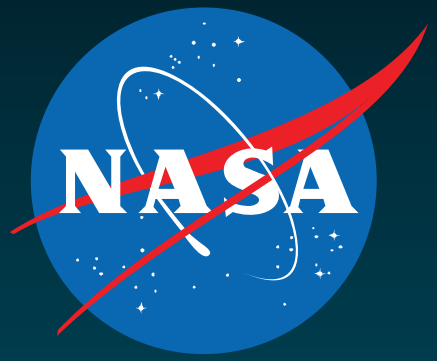
Enforce comprehensive part development plans

- Design & Assessment
- Materials & Processes
- Inspections
- Testing

Verify individual build lot quality

- Lot acceptance for strength, chemistry, microstructure
- Proof testing
- NDE

Develop/adopt design and process specifications



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